CHAPTER THIRTY. *

ACTINOMETRY OF THE PHOTOGRAPHIC INTENSITY OF ARTIFICIAL LIGHT SOURCES.

Historical Review

Only inadequate comparisons have been made of the relative chemical illuminating power of different light sources. Most of the older comparative measurements are of only limited value, because they seldom state either the quantity of material consumed or the dimensions of the flame, and, moreover, the observed results were generally not reduced to a common basis for comparison.

Among these are the experiments of Riche and Bardy, who investigated limelight, magnesium light, zinc, sulphur, carbon disulphide burning in oxygen, and similar sources, and found them to be especially effective for bromide-collodion and dry plates. (Bull. Soc. franç., 1875; *Photographic News*, 1875, p. 171.) Stebbing gives similar values (*Photographische Mittheilungen*, vol. 12, p. 103).

The extraordinary inaccuracy of the information concerning the consumption of the combustible materials, however, led to contradictions. Thus, oxygen–carbon disulphide flame was repeatedly declared to be more effective than magnesium light; Lossen, on the other hand, explained this result as incorrect on the basis of his own experiments with bromide plates, and regarded magnesium light as the more effective source [1].

McLellan burned various substances (sulphur, sulphides of sulphur and antimony, phosphorus, magnesium, etc.) in a glass vessel filled with oxygen (about 6–7 litres) and investigated their photographic effectiveness on bromide-gelatine plates by placing a scale photometer over the plate (*British Journal of Photography*, 1881, p. 634). He found that the actinic power of the light from burning substances is considerably greater when combustion takes place in oxygen rather than in ordinary atmospheric air.

According to H. W. Vogel, the effect of the Sell's lamp on photographic plates is approximately four times weaker than the light of a clear winter day at midday. Compared with other artificial light sources, however, it has the advantage that, owing to its predominantly blue colour, it does not dazzle the eyes—a point of some importance in portrait photography [2].

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* **Josef Maria Eder**, *Ausführliches Handbuch der Photographie*, 3rd edition, Volume I, Part 3: *Photographie bei künstlichem Lichte, Spektrumphotographie, Aktinometrie* (Wilhelm Knapp, Halle a. S., 1912).

1) *Photographisches Archiv*, 1878, p. 70.

2) *Berichte der Deutschen Chemischen Gesellschaft*, 1875, p. 96.

Ignition compositions (Indian white fire [1]) permit the photographing of illuminated persons in approximately two to four times the exposure normally required in average daylight. Magnesium flash powder, however, acts in a much shorter time.

The light from the best and brightest phosphorescent substances is comparatively weak. When allowed to act directly on a bromide-gelatine plate, it has approximately the same effect as the light of an ordinary candle at a distance of 50 cm. The phosphorescent light is always much weaker than the light that originally excited the phosphorescence.

Gaedicke found that 102 g of a magnesium chlorate–sulphur–antimony flash powder, at a distance of 1 metre, produced on albumen paper in one second a photographic effect equal to that of the sun (*Photographische Mittheilungen*, 1887, p. 109).

Burning magnesium possesses approximately the same chemical action as the sun without clouds at an altitude of 10°, provided that both light sources have the same apparent area. This condition is fulfilled when a magnesium disc 1 cm in diameter is placed 10.7 m from the illuminated object. At a solar altitude of 22.4°, however, the chemical action of the sun is 36 times greater than that of the magnesium light (Bunsen and Roscoe).

Abney compared the photographic effectiveness of various light sources by means of platinotype paper. He found that electric light having a visual brightness of 1 normal candle is photographically equivalent to 10.7 candles acting for one minute. One English grain of magnesium (= 0.065 g) has a photographic effect equal to 23.1 normal candles acting for one minute. An oxygen–hydrogen limelight of 400 candlepower has a photographic value equivalent to 800 candles; with such illumination a platinotype may be copied in 5 seconds. At equal visual brightness, Abney found that electric light was four times stronger photographically than magnesium light. For example, an electric arc lamp having a visible brightness of 1,150 candles is photographically equivalent to 12,300 candles for copying, acting for one minute. Such a light will produce a platinotype copy at a distance of 30 cm in 10 minutes. If magnesium ribbon burning at a rate of 124 grains per minute is used at the same distance, an exposure of 40 minutes is required, although its apparent brightness is equal to that of the electric light just mentioned. This entails a consumption of about 370 g of magnesium during the 40-minute exposure. In sunlight, by contrast, the copy would require only about 1 minute. It follows that, next to sunlight, the electric arc lamp is the most suitable light source for prolonged photographic printing, whereas magnesium is less well suited for this purpose (*Bulletin Belge de Photographie*, 1891, p. 538; *Eder's Jahrbuch für Photographie*, 1892, p. 379).

For the investigation of the photographic effect of an artificial light source, it is customary to use the Hefner amyl acetate lamp as the standard comparison light source, and, at a distance of 1 metre with an exposure time of 1 second, to determine its relative photographic effect.

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1) With a consumption of approximately 30 g in 10 seconds.

For the characterization of light sources, it is important to know the ratio of their photographic effectiveness to their optical brightness; that is, the so-called relative actinity (see p. 81).

The ratio of the photographic effectiveness of an artificial light source to that of the Hefner standard lamp (HE) is determined by means of Scheiner's sensitometer, or a similar instrument. Using the same type of photographic plate and developing both plates under identical (simultaneous) conditions, one first determines the approximate relative brightness of the two light sources from the sensitometer readings. One then calculates the distance at which the light source under investigation must be placed in order to produce, in the same exposure time, the same photographic effect as the Hefner lamp. After a few trials, this distance is verified experimentally and established with confidence. The photographic effectiveness of the light source, expressed in Hefner units, can then readily be calculated according to the inverse-square law.

In a similar manner, scale photometers or tube photometers (used for determining the brightness of light diffused by white paper reflectors or ground glass) may be employed for actinometric measurements.

It should always be remembered that the actinity value applies only to a particular photographic emulsion, for example the bromide-gelatine emulsion most commonly used. The relative actinity of two light sources varies with the composition of the light-sensitive layer. It is different for silver bromide than for silver chloride, changes greatly when photographic emulsions are sensitised with dyes (orthochromatic plates), and is often different again for chromotype papers than for silver printing papers.

1. Chemical Brightness of Various Light Sources Relative to Bromide-Gelatine (Developing Plates) and the Hefner Lamp

For photography by artificial light, the photographic brightness of various light sources, measured on bromide-gelatine dry plates, is of particular importance. If the photographic effectiveness of the light sources, at a distance of 1 metre, is compared with that of a Hefner standard lamp, the results obtained by Eder are given in the following table.

On chloride-gelatine developing plates, 1 mg of magnesium ribbon burned in air has a photographic effect equal to 872 second-metre-candles. On orthochromatic (erythrosine-sensitised) bromide-gelatine plates, 1 mg of magnesium has a photographic value of only 192 second-metre-candles, because the yellow-

Light source used (at a distance of 1 m)	Relative optical brightness	Exposure time (s)	Chemical illuminating power (photographic effectiveness), relative to the Hefner lamp
1. Hefner-Alteneck amyl acetate lamp	1	1	1
2. Drummond limelight (lime, magnesia or zirconia)	70	1	260
3. Gaslight (Argand burner)	16	1	28
4. Auer incandescent gaslight	60	1	152
5. Electric arc light	400	1	4000
	Chemical illuminating power (photographic effectiveness), expressed in second-metre-candles (Hefner units)		
6. Magnesium ribbon burning in air and falling directly upon bromide-gelatine; brightness per 1 mg Mg	435 SMH [1]		
7. The same after passing through a colourless glass plate	270–325		
8. Magnesium flash powder after passing through a colourless glass plate, per 1 mg Mg	385		
9. Magnesium flash with permanganate, or Müller's chlorate-perchlorate mixture, per 1 mg Mg	200		
10. Magnesium ribbon burning in oxygen, per 1 mg Mg	769		
11. Equal parts aluminium powder and potassium perchlorate, per 1 mg Al	232		
12. Phosphorus burning in air, per 1 mg	2¾		
13. Phosphorus burning in oxygen, per 1 mg	85		

green-sensitive plates behave more favourably towards the yellowish light of the amyl acetate lamp than towards magnesium light, whose chemical effect is therefore somewhat reduced.

From these figures it follows that Drummond limelight, although appearing to the human eye 70 times brighter than a candle, possesses a photographic effectiveness on silver bromide that is 260 times greater than that of the candle. Similarly, gaslight appears visually about 16 times brighter than a candle, yet acts 28 times more strongly on silver bromide. A burning magnesium ribbon (of the type described above) has a chemical illuminating power approximately 24 times greater than its apparent visual brightness would suggest. On bromide-gelatine it is photographically nearly 2,000 times more effective than a candle. This agrees with the observation of Michalke (*Photographische Mittheilungen*, 1890, vol. 24, p. 195) that the diffused light of the sky, although having the same apparent brightness as an amyl acetate lamp, is nevertheless ten times more effective on bromide-gelatine than the latter.

If the chemical illuminating power is calculated in second-metre-candles, and the effect that would result if

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1) SMH = Sekunden-Meter-Hefnereinheiten (second-metre Hefner units).

the light is allowed to act for *one second*, the following values are obtained (Eder):

Light source	Relative effect on bromide-gelatine, expressed as second-metre-candles
1. Standard candle (Hefner unit)	1
2. Magnesium flash, produced by burning 1 g of magnesium, after passing through colourless glass (photographic objective)	200,000–300,000

If one considers that "good light" in a photographic studio produces, on the horizontal photometer, an average chemical effect of 50,000 to 100,000 second-metre-candles, that direct sunlight (falling perpendicularly upon the photometer) during experiments made on 24 October 1890 at 9 a.m. in Vienna, under an almost cloudless sky, produced an effect of 450,000 second-metre-candles, and that the electric arc light from four lamps, each of 2,000 candlepower (that is, together 8,000 candles of visual brightness), possesses a chemical illuminating power on bromide-gelatine of approximately 80,000 candles, it follows that magnesium powder, among all artificial light sources known up to that time, produces the greatest relative chemical effect during its extremely short duration of combustion.

One may state with certainty that, next to sunlight, magnesium light and electric light are the most photographically effective light sources. The electric arc, when operated with several thousand candles of luminous intensity, acts upon bromide or iodide silver plates almost as energetically as sunlight, and upon iodide salts even more energetically, since it decomposes them [1]. Magnesium light is so intensely actinic that 4–5 g of magnesium powder, burned within a fraction of a second, develops a chemical illuminating power equivalent to about one million candles.

Under electric light, plants grow and respire in the same manner as in sunlight or daylight [2], and certain organic substances, such as red blood albumin, are decolourised by electric light within 24 hours to the same extent [3]. (See Chapter XII.)

2. Chemical Illuminating Power and Photographic Effectiveness of the Various Forms of Magnesium Light

Magnesium ribbon burns much more slowly than magnesium powder, and the amount of light produced is probably proportional to the weight

1) S. Leeds, *Chemical News*, vol. 42, p. 147; supplement to *Annalen der Physik und Chemie*, 1880, p. 730. See also the *Ausführliches Handbook der Photographie*, 2nd edition, Vol. I, Part 2, p. 369.

2) Siemens, *Photographische Korrespondenz*, 1880, vol. 17, p. 69.

3) *Chemiker-Zeitung*, 1881, p. 97, from *Moniteur des produits chimiques*, vol. 2, p. 402.

of the magnesium that has been burned, but the relationship is by no means directly proportional. Nor is it immaterial whether the same weight of magnesium is burned in the form of ribbon (that is, over a longer period), as pure magnesium powder in a flame, or as part of an explosive mixture.

For rough estimation—which nevertheless serves as a useful practical guide in photography—it may be assumed that the photographic effect produced by the same weight of burned magnesium is approximately the same, regardless of the form in which it is burned. Thus, if twice, three times, or four times as much magnesium is burned, the exposure may be reduced to approximately one-half, one-third, or one-quarter of the original exposure time. Although the practical photographer may find such an approximate rule satisfactory, it does not withstand more exact examination.

If one compares the chemical illuminating power of equal weights of slow-burning magnesium ribbon and rapidly burning pure magnesium powder, it is found that the two are only approximately, but not exactly, equal. Magnesium powder dispersed in a flame develops a more effective light. In contrast, the illuminating power of magnesium powder mixed with oxygen-yielding substances (such as chlorates) and ignited in a heap remains below that of pure magnesium powder dispersed in a flame (by almost one-half), and scarcely reaches the illuminating power of an equal weight of slowly burning magnesium ribbon.

The reason for this striking phenomenon probably lies in the following. The flame of burning magnesium is surrounded by a cloud of white magnesium oxide (MgO), which is almost opaque to light falling upon it or emerging from the burning magnesium. Consequently, when several magnesium ribbons burn simultaneously close together—or similarly when a heap of magnesium–chlorate mixture burns—the rear portions contribute scarcely any additional light beyond that emitted by the foremost burning layer. The closer the burning magnesium particles lie together, the more compact the burning mass, and the less increase in light output is obtained. For example, a compact heap of magnesium–chlorate powder yields only about two-thirds to three-quarters of the light produced by the same quantity spread out in the form of a long strip. Likewise, six closely wound magnesium ribbons produce only about half the light effect of the same quantity of ribbon when burned successively, or when the wires are ignited side by side at some distance from one another. This readily explains why the smaller luminous surface of a compact heap of magnesium in an explosive mixture emits less light than the much broader luminous surface of magnesium powder dispersed throughout a flame like a cloud of dust. Intermediate between these two extremes lies the slow-burning magnesium ribbon, which burns with only a small flame.

In more recent years, Eder carried out accurate photometric investigations into the chemical brightness of burning magnesium, aluminium, and phosphorus (*Proceedings of the Imperial Academy of Sciences in Vienna*, Mathematical–Natural Science Class, 1903, vol. 112, Section IIa, p. 249).

We reproduce this work in the following pages.

A) Photometry of Magnesium Light

Burning magnesium ribbon has frequently been used as a standard light source in photochemical investigations ever since Bunsen and Roscoe showed, about half a century ago, that the combustion of magnesium provides a simple and reliable means for photometric measurements.[1] According to their observations, magnesium wire longer than 10 mm burns with a constant luminous intensity, whereas shorter lengths exhibit a relatively lower visual brightness. Bunsen and Roscoe themselves, however, pointed out that their determinations of visual brightness were not entirely accurate because the colour of magnesium light differed considerably from that of candlelight in the grease-spot photometer they employed. According to Roscoe, magnesium wire burning at a rate of 0.12 g per minute and having a length of 0.987 m produces a luminous intensity of 74 standard candles. Bunsen also found that combustion in oxygen greatly increases the brightness of magnesium light, raising it to 110 candles.[2]

According to Troost, magnesium wire 97 mm long and 0.33 mm thick develops a luminous intensity (visual brightness) of 64 candles while burning in air, increasing to 110 candles when burned in oxygen.[3]

Some years earlier, Eder attempted to measure the photographic effectiveness of magnesium light for photographic purposes.[4] Using the Warner sensitometer, which at that time was sufficiently accurate for technical applications, he found that 0.05 g of magnesium produced on bromide-gelatine plates a chemical illuminating power of 11,400 candle metre-seconds (referred to Hefner candles, or HMK). Eder later discovered that the coloured scales of the Warner sensitometer affected the quality of the light, and therefore insisted that, in sensitometric experiments, the light under investigation should fall directly upon the plate without passing through coloured scales.[5]

For practical photographic work, however, these differences are of comparatively little importance, provided that all other conditions remain the same.

The suitability of magnesium light as a photometric standard for precise photometric investigations has therefore not yet been fully established, and, as I shall show, it cannot be employed for this purpose without reservation.

B) Determination of the Visual Brightness of Magnesium Ribbon Burning in Air

In Eder's experiments (which agreed with those of Bunsen), a short length of burning magnesium ribbon exhibited a lower visual brightness than a long length. The probable explanation is that, as the ribbon burns, it bends downward under its own weight, so that the burning portion gradually becomes longer. For this reason, the ribbon should be burned in a magnesium lamp fitted with a clockwork feed mechanism. Even with such an apparatus, however, the measured brightness becomes disproportionately greater when a long hanging length of magnesium burns simultaneously, apparently because the flame temperature increases.

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1) Bunsen and Roscoe, Poggendorff's *Annalen der Physik*, **Vol. 101**, p. 235; Ostwald's *Klassiker der exakten Wissenschaften*, No. 38.
2) *Annalen der Chemie und Pharmacie*, 1852, Vol. 82, p. 144.
3) Poggendorff's *Annalen der Physik und Chemie*, 1865, Vol. 201, p. 644.
4) Eder, *Ausführliches Handbuch der Photographie*, 2nd edition, Vol. I, Part 3, p. 457.
5) See Eder's paper: *System der Sensitometrie photographischer Platten* ("System of the Sensitometry of Photographic Plates"), Sitzungsberichte, Vol. 108, Section IIa, 1899.

Eder employed in his experiments a precision optical bench, constructed by Krüss, fitted with interchangeable green and red filters in accordance with Weber's method.[1] In this way, from the ratio of the brightness measured through the green and red filters, Eder was able to determine the visual brightness of burning magnesium with greater accuracy than Bunsen and Troost.

In Eder's experiments, magnesium ribbon, burning at a rate of 7.4 mg per second (in the clockwork-fed lamp), produced a visual brightness of 135 Hefner candles.[2] Within narrow limits, the visual brightness is proportional to the quantity of magnesium burned per second.

C) Determination of the Chemical Brightness of Burning Magnesium

For his measurements of the chemical brightness of burning magnesium ribbon, Eder clamped the ribbon horizontally with its narrow edge uppermost and ignited it by means of a Bunsen burner, the chimney of which deflected the flame so that it touched only the tip of the ribbon.

The method of ignition is not without influence on the photometric effect of the total quantity of magnesium burned.[3] A piece of magnesium held in the flame burns slowly; if it is inserted too deeply, it melts and chars without burning brightly, and this portion therefore contributes less light. Furthermore, the combustion product (MgO) forms a kind of tube which hinders the escape of light. Thus several sources of irregularity in light emission arise, becoming more troublesome the shorter the magnesium ribbon.

a) Direct Magnesium Light Incident on Bromide-Gelatine

A piece of magnesium ribbon [4] weighing 2.6 mg was burned at a distance of 44.5 m in front of a bromide-gelatine plate, and its effect was compared with that of a Hefner amyl acetate lamp placed 12 m away, using progressively increasing exposure times from ½ to 3 minutes. The developer was ferrous oxalate.

The resulting density was measured, and for bromide-gelatine the chemical brightness was found to be: 1 mg magnesium = 435 Hefner metre-seconds (HMS).

b) Direct Magnesium Light Incident on Chloride-Gelatine

This was examined under similar conditions. 13–16 mg of magnesium were burned at distances of 3–5 m.

The chemical brightness was found to be: 1 mg magnesium = 872 HMS.

c) Relative Actinity of Magnesium Light for Silver Bromide and Silver Chloride

If the visual brightness of magnesium light is taken as 135 Hefner candles, for a combusion rate of 7.4 mg of magnesium per second, then this quantity of magnesium would be

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1) L. Weber's photometer, manufactured by Franz Schmidt & Haensch, Berlin.

2) Hefner amyl acetate lamp, calibrated by the Physikalisch-Technische Reichsanstalt, Charlottenburg.

3) Englisch suspended pieces of magnesium ribbon from the ends of a wire star so that, as the star rotated, the pieces successively entered the tip of the Bunsen flame. Nevertheless, fluctuations of more than 5% in light intensity about the mean value were occasionally observed. (Englisch, *The Law of Blackening of Bromide-Gelatine*, 1901.)

4) One centimetre of the magnesium ribbon used by Eder weighed, on average, 0.0065 g.

would exert a chemical effect is: 435 × 7.4 = 3219 HMS on silver bromide, 872 × 7.4 = 6453 HMS on silver chloride-gelatin.

From this follows the relative actinity [1] of magnesium light (magnesium burning in air): for Bromide-gelatine: 23.8; and for Chloride-gelatine: 47.8

d) Chemical Action of Magnesium Light (Burning in Air) After Passing Through Colourless Glass, on Bromide-Gelatine

Eder employed a tube photometer of his own design,[2] in which the apertures do not increase in arithmetical progression, as in H. W. Vogel's tube photometer, but in steps of brightness corresponding to a geometric progression, exactly matching Scheiner's sensitometer scale, namely: 1 : 1.27.

In Eder's tube photometer, the lowest brightness is produced by an aperture 0.5 mm in diameter at the end of a 10 cm long tube (No. 20 of Eder's photometer), whereas the brightest stage (No. 1) has 25 apertures, each 1 mm in diameter. The brightness limits therefore extend from 1 to 100. The incident light must first be diffused, so that the photographic plates placed at the opposite ends of the tubes are uniformly exposed.

Following Vogel's method, the light may be diffused by reflection from white paper. Using Eder's tube photometer at a distance of about 1 metre from the white drawing paper, in the vicinity of a room window, exposures of a few seconds are sufficient. For his own experiments, however, Eder interposed six sheets of ground, colourless plate glass. These attenuated the ultraviolet below $\lambda < 3800$ Å, and completely absorbed it below $\lambda < 3300$ Å, thereby reducing the chemical action of magnesium light, relative to the amyl acetate lamp.

These conditions, however, closely correspond to those encountered in practical photography (absorption of light by photographic objectives, etc.). Little useful photographic action is lost because the light from burning magnesium oxide does not extend very far into the ultraviolet,[3] and already below approximately $\lambda = 3600–3400$ Å it produces little effective photographic action.

In the following experiments, short pieces of magnesium ribbon only 1 cm long occasionally exhibited fluctuations in chemical brightness of as much as ±20% under unfavourable conditions. With longer pieces, the fluctuations were smaller (about 10%) and could be further reduced by ensuring a more uniform rate of combustion.[4] Under favourable conditions, however, Eder also observed fluctuations of only about ±7%.

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1) That is, the ratio of photographic brightness to optical brightness. See Eder's paper *System der Sensitometrie photographischer Platten*, Part III, 1901, *Sitzungsberichte*, Vol. 110, Section IIa, p. 1103.

2) Eder based his system of sensitometry on Scheiner's photometer, and consistently employed it throughout these investigations.

3) See Eder, "Das Flammen- und Funkenspektrum des Magnesiums" (*The Flame and Spark Spectrum of Magnesium*), *Denkschrift der kaiserlichen Akademie der Wissenschaften, Wien*, 1903.

4) The reason why longer magnesium ribbons produce a more constant brightness than very short pieces may lie in the fact that disturbances (attenuation) of the light emission occur chiefly during the initial phase of ignition and again when the last remnant of the magnesium ribbon burns away. If, instead, a progressive exposure is made by successively burning several 1 cm lengths of magnesium ribbon,

Chemical Illuminating Power of Magnesium Light Burning in Air After Passing Through Colourless Glass

Measured on bromide-gelatine and compared with amyl acetate light

Weight of magnesium burned	Length of magnesium ribbon	Photographic effect per 1 mg magnesium (HMS)
0.005–0.007 g	1 cm	270 HMS
0.030 g	5 cm	285 HMS
0.065 g	10 cm	325 HMS

As can be seen from this table, short pieces of magnesium ribbon produce relatively less light than longer pieces.[1] With ribbons approximately 20 cm long, I observed in several cases a chemical brightness of more than 400 HMS per 1 mg of magnesium.

From these results it follows that the light produced by ten separate 1 cm pieces of magnesium ribbon must never be regarded as equivalent to the light produced by a single 10 cm length burned continuously.

e) Magnesium Light (Burning in Air) on Orthochromatic Plates

In another series of experiments, Eder compared the effect of 46–104 mg of magnesium ribbon, burned at distances of 1–7 m, with that of an amyl acetate lamp at a distance of 1 m and an exposure time of 5–10 minutes, using a tube photometer fitted with six ground-glass diffusers, on orthochromatic plates.

He found that 1 mg of magnesium produced an average effect of 192 HMS on erythrosine-sensitised plates (silver bromide-gelatine + erythrosine). Consequently, for yellow-green-sensitive orthochromatic plates, magnesium light is not nearly as much more powerful than amyl acetate light as it is for ordinary photographic plates, which are sensitive only to blue-violet and ultraviolet radiation.

Accordingly, the relative actinity of magnesium light is also reduced considerably and is much lower than for ordinary bromide plates.

f) Magnesium as a Standard Light Source for Photography and the Sensitometry of Photographic Plates

The strong magnesium oxide emission bands occurring in the spectrum of burning magnesium at λ 5007–4900 Å, together with the comparatively weaker green magnesium triplet at λ 5183–5167 Å, interrupt to a considerable extent the continuity of the visible continuous spectrum emitted by the white-hot, powdery magnesium oxide. These green spectral lines are so prominent that in

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careful measurements of the blackening of the exposed photographic plates show that the exposure effect is variable and may sometimes give the illusory appearance of periodicity. Underestimating or neglecting this phenomenon may lead to erroneous conclusions.

1) Englisch likewise found the same result and stated that the chemical light intensity is proportional to the ribbon length only for short pieces of magnesium ribbon, not for longer ones, although he did not determine the total quantity of light photometrically with greater precision (loc. cit.).

photometric (sensitometric-photographic) measurements, the green region of the spectrum appears much brighter relative to the blue-violet region than it does in diffuse daylight.[1]

To investigate this effect, Eder compared the relative brightness of daylight reflected from white paper with that of magnesium light, using orthochromatic plates (sensitised to yellow-green with erythrosine) and placing spectrally well-characterised blue and yellow filters in front of the plates.[2] He found that the plates were twice as sensitive to the yellow-green component of magnesium light as to that of daylight, when the two light sources had first been adjusted to produce the same photographic effectiveness in the blue-violet region.

Consequently, if the relative green and blue sensitivity of a photographic emulsion is determined actinometrically using magnesium light, the resulting values are not valid for diffuse daylight. This makes it difficult to employ burning magnesium as a standard light source for photometric or sensitometric-photographic purposes in a manner consistent with daylight, unless one confines oneself to photographic materials that are sensitive only to blue-violet light. Once orthochromatic plates, or other materials whose green sensitivity is significant, are employed, the discrepancy becomes important.

Amyl acetate or benzine light, both of which possess a continuous spectrum, can be related to daylight much more readily for photometric purposes than the spectrum of burning magnesium, which is broken up by a number of intense emission bands. Because of this property, magnesium light is even less satisfactory than the ordinary electric carbon arc, whose spectrum is likewise not perfectly continuous.[3]

For these reasons, the system of absolute sensitometry for photographic plates proposed by H. W. Vogel, in which a tube photometer employed a sheet of white paper illuminated by magnesium light as the standard light source,[4] cannot be recommended. Nor is it suitable for the relative sensitometry of photographic plates having markedly different colour sensitivities, because of the spectral composition of magnesium light already discussed. Moreover, burning magnesium falls far short of the ideal of a constant standard light source.

g) Magnesium Burning in Oxygen

Magnesium burned in oxygen produces considerably more light than when burned in air, as already reported by Bunsen, Troost, Abney, and others.[5] This greater brightness led to the use of oxygen-burned magnesium light for photographic exposures.[6]

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1) See Eder's paper: "*Das Flammen- und Funkenspektrum des Magnesiums*" (The Flame and Spark Spectrum of Magnesium), 1903.

2) The filters were copper-ammonia oxide and potassium monochromate, as described in Eder's "*System der Sensitometrie photographischer Platten*" (System of the Sensitometry of Photographic Plates).

3) Bremen light (*Bremerlicht*), with its strongly developed calcium emission arc, exhibits even greater spectral discontinuity than magnesium light.

4) Eder, *Ausführliches Handbuch der Photographie*, 2nd edition, Volume I, Part 2, p. 413.

5) Abney, *Instruction in Photography*, London, 1892, p. 266. According to Abney, the photographic effect of one English grain of magnesium ribbon burned in oxygen is equivalent to that of 6–12 grains of magnesium burned in air.

6) M. Kiesling, *Photographische Mittheilungen*, Vol. 35, p. 137; Vol. 36, p. 392. For further experiments see Eder's Jahrbücher für Photographie; also Eder, *Ausführliches Handbuch der Photographie*, 2nd edition, Volume I, Part I, pp. 501–502.

Since more accurate actinometric investigations were lacking, Eder burned magnesium ribbon in a one-litre flask filled with oxygen (ignited by passing a strong electric current) and determined its effect in parallel with an identical quantity of magnesium burned in a flask filled with air. In both cases, the attenuation caused by smoke and the glass vessel was therefore essentially the same. Under these relatively unfavourable conditions for light emission, 1 mg of magnesium ribbon burned in air produced, on bromide silver, a photographic effect of 266 HMS, whereas 1 mg of magnesium burned in oxygen produced 769 HMS. Thus, combustion in an oxygen-filled flask approximately triples the photographic effect of burning magnesium on bromide silver, although absorption by the glass vessel also plays a part.

h) Magnesium Powder Blown Through a Gas Flame (Magnesium Powder Light)

If magnesium powder is blown through a Bunsen gas flame (using 0.02–0.05 g of magnesium), then 1 mg of the burned magnesium powder, depending on the manner in which it is blown through and consumed, produces on bromide silver, after passing through colourless glass (under conditions analogous to those of experiment d), a chemical effectiveness of 294, 472, and 389 HMS, respectively, giving an average of 385 HMS.

Thus, for the same quantity of magnesium burned, magnesium powder light develops, on average, slightly more effective light than magnesium ribbon burned in air. For practical photographic purposes, however, this difference is of little importance.

i) Magnesium Mixed with Oxygen-Yielding Substances (Magnesium Flash Powder)

It is well known that magnesium, when mixed with oxygen-rich substances (chlorates, nitrates, permanganates, etc.), burns readily with a brilliant light (flash powder).

Very small quantities of such flash powders burn irregularly. However, if 1–2 g, and preferably 3–4 g, of magnesium powder are used (with an appropriate addition of oxygen-yielding substances), more satisfactory results are obtained and the quantity of light produced becomes reasonably constant.

For practical photographic purposes, it may be assumed that the amount of light developed depends primarily upon the quantity of magnesium metal burned.

Photometric measurements, however, show that the relative actinity for different photographic materials depends upon the nature of the oxygen-yielding salts mixed with the magnesium, and is also influenced by the emission spectrum of these metallic salts.

For example, magnesium mixed with equal parts potassium nitrate produces on bromide silver only three-quarters of the photographic effect obtained from the same quantity of magnesium mixed with potassium permanganate.[1]

Müller's magnesium flash powder, consisting of chlorate + perchlorate,[2] is equally effective as the permanganate mixture. In Eder's experiments, 2 g of magnesium powder in either of these two mixtures produced a total effect of 400,000 HMS, or 200 HMS per 1 mg of magnesium. Thus, it is less effective than magnesium powder light, and still less effective than magnesium burned in oxygen.

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1) Four parts magnesium powder, mixed with three parts powdered dry potassium permanganate.

2) 30 parts potassium perchlorate, 30 parts potassium chlorate, and 40 parts magnesium powder. (See Eder, *Ausführliches Handbuch der Photographie*, 2nd edition, Vol. I, Part 3, p. 515.)

Thus, magnesium powder blown through a flame (*powder light*) produces a greater photographic effect with relatively less smoke than the magnesium flash powders just described.

Nevertheless, these explosive flash powders show no poorer constancy of brightness than magnesium ribbon. Indeed, because they burn explosively and disperse widely during combustion, they behave more favourably than magnesium burning slowly in a compact mass.

D) Chemical Brightness of Burning Aluminium

Sheet aluminium, heated to incandescence by an electric current, burns rather poorly in air, producing only a moderate amount of light; in oxygen, however, it burns with great luminous intensity and almost explosively.

The great brightness of aluminium burning in oxygen was first observed many years earlier by Wöhler[1], then by Gorup-Besanez[2], while Martin Kiesling[3] employed aluminium sheet burning in oxygen for photographic exposures.

In Eder's measurements, 1 mg of sheet aluminium burning in air produced an effect (on bromide silver) of only 14 HMK.[4]

In contrast, 1 mg of aluminium[5] burned in oxygen gave a chemical brightness of 715–824 HMS for ordinary bromide-gelatine.

In experiments with orthochromatic plates (erythrosine-sensitised bromide-gelatine), aluminium did not exhibit the same great superiority over amyl acetate light; instead, 1 mg of aluminium corresponded to 368 HMS.

Aluminium powder, mixed in equal parts with potassium perchlorate, produces an excellent flash powder. Quantities of 0.2–0.4 g burn well, yielding, for 1 mg of aluminium, a light having a photographic effectiveness of 232 HMS (for bromide-gelatine).

E) Chemical Brightness of the Light from Burning Phosphorus

When 0.3 g of phosphorus is burned in oxygen in a large, thin-walled beaker,[6] it develops a dazzling white light. The chemical brightness for bromide silver amounts to 84.5 HMK per 1 mg of phosphorus. This value is a minimum, because a considerable amount of smoke remained within the beaker.

Under otherwise similar conditions, phosphorus burning in air produces a chemical brightness of only 2.8 HMK per 1 mg of phosphorus.

Thus, phosphorus light, compared with magnesium and aluminium light, is of no practical importance as a source of chemically active radiation.

Chemical Illuminating Power (for Bromide-Gelatine) and Burning Duration of Various Magnesium Flash Powders

Following Eder's work, Fr. Novak carried out accurate measurements of the chemical illuminating power and burning duration of various magnesium flash-powder compositions.[7] We reproduce the results of his investigation below.

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1) *Poggendorff's Annalen*, Vol. 11, p. 146.

2) *Annalen der Chemie und Pharmacie*, 1867, Vol. 142, p. 376.

3) *Photographische Mitteilungen*, Vol. 37, p. 102.

4) Several sheets of aluminium weighing 0.03–0.06 g were burned, and the effect per 1 mg was calculated from the results.

5) The measurements were made in a glass flask, using a photometer fitted with six glass plates.

6) Ignition was accomplished by external heating.

7) *Photographische Korrespondenz*, August 1907.

The determination of the photographically effective quantity of light was carried out using Eder's tube photometer (see p. 186), ordinary bromide-gelatine dry plates being employed as the recording medium. In this way, the chemical illuminating power on bromide-gelatine was determined in candle-metre-seconds (HMS), referred to the Hefner amyl acetate lamp as the standard. Three discs of ground glass were placed in front of the sensitometer, and the flash powder was ignited electrically at a distance of 6 m from the sensitometer. Each flash-powder composition investigated contained 1 g of magnesium.

The burning time was determined using Rhede's apparatus (see p. 610).

With regard to the preparation of the flash-powder mixtures, it should be noted that each additive was first finely powdered separately and only then mixed with the magnesium powder on glazed paper. This precaution is of the utmost importance because some flash-powder mixtures are liable to ignite through friction or shock.

The following table contains the experimental results. It should be noted that mixtures of magnesium powder with cadmium nitrate and zinc nitrate had apparently not been investigated previously.

Relative Chemical Illuminating Power of Magnesium Flash Mixtures

Mixture containing 1 g magnesium with the following thoroughly dried compounds	Relative chemical illuminating power on bromide-gelatine (HMS)	Burning time (s)
¾ g Potassium permanganate	173,000	0.120
1 g Potassium nitrate	36,000	0.070
1 g Barium nitrate	60,000	0.070
1 g Strontium nitrate	84,000	0.105
1 g Thorium nitrate	281,000	0.220
¾ g Thorium nitrate	332,000	0.230
½ g Thorium nitrate	358,000	0.240
1 g Zirconium nitrate	237,000	0.240
1 g Cerium nitrate	173,000	about 1 second
1 g Zinc nitrate	173,000	0.250
½ g Zinc nitrate	282,000	0.270
1 g Slightly basic cadmium nitrate	399,000	0.300
1 g Tungstic acid	20,000	about 1 second
1 g Ammonium molybdate	86,000	about 1 second

Among the mixtures investigated, the one containing cadmium nitrate produced the greatest chemical illuminating power (photographic effectiveness on bromide-gelatine after the light had passed through glass). It was followed by the mixture containing thorium nitrate.

The table further shows that varying the proportion of thorium nitrate alters the illuminating power; the most favourable proportion is ½ part thorium nitrate to 1 part magnesium powder.

Cerium nitrate is unsuitable for flash powders, since it burns too slowly. Owing to its comparatively high illuminating power, however, it might prove suitable for lighting mixtures, although its burning rate would probably have to be reduced further by the addition of small quantities of inert substances.

The mixture consisting of ½ part dry zinc nitrate and 1 part magnesium powder may also be regarded as excellent.

The mixtures containing tungstic acid and ammonium molybdate are of no practical importance, owing to their low illuminating power and slow rate of combustion.

With regard to the burning rate, the mixtures containing potassium nitrate and barium nitrate burned the fastest of those examined. The mixtures that produced the greatest illuminating power—namely those containing cadmium nitrate and thorium nitrate—burned approximately four and three times more slowly, respectively, than the potassium nitrate mixture. In practical photography, however, these burning rates are still entirely adequate for producing satisfactory exposures. Moreover, these mixtures possess the advantage of a photographic effectiveness on bromide-gelatine more than nine to ten times greater than that of the potassium nitrate mixture.

With regard to the amount of smoke produced, the experiments showed that, in general, the greater the illuminating power, the less smoke was evolved. Of the flash-powder mixtures investigated, the potassium nitrate mixture produced the most smoke, whereas the thorium nitrate and cadmium nitrate mixtures produced the least.

For further information on the relative chemical illuminating power and burning duration of various flash-powder compositions, see the work of Franz Novak, p. 557.

On the Actinity of Various Electric Arc Lamps for Photographic Copying

Paul von Schrott [1] carried out detailed investigations of this subject.

His work dealt principally with Dr. Küch's mercury-quartz lamp, then with ordinary mercury-vapour lamps, and finally with various carbon arc lamps. The measurements of chemical brightness were made using Vogel's silk-paper photometer and the normal colour photometer.

When the silk-paper photometer was employed, it was found that the assumption commonly made in photographic practice—that the absorption constant of such a photometer is the same for every light source—is incorrect. Instead, the constant has a different value for each light source because short-wavelength violet light is absorbed more strongly by the silk paper than long-wavelength light.

Whereas the constant for illumination by a Scheiner benzine lamp, using bromide-gelatine, was 1.283, the corresponding values, using the chloride-silver standard paper described later, were:

- Incandescent lamp: 1.36
- Red carbon arc: 1.486
- Quartz lamp: 1.74

Because the Vogel photometer was covered with a glass plate, ultraviolet rays of wavelengths below $\lambda = 300$ nm were absorbed and therefore did not contribute to the measurements. This is entirely appropriate in view of the glass plates used in practical photographic copying frames.

As the standard paper, Eder employed his standard chloride-silver aluminium nitrate paper [2] (see p. 144).

As the standard colour, he used Bunsen's normal colour, consisting of 1 part ruby (Rubin) and 1000 parts zinc oxide, applied to white card with a very dilute gelatine solution.

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1) *Photographische Korrespondenz*, September 1909; *Zeitschrift für wissenschaftliche Photographie*, 1909; *Eder's Jahrbuch für Photographie*, 1910, p. 351.

2) *Photographische Korrespondenz*, 1909, July issue.

Light source	Total light intensity	Power source	Power source+ ballast	Efficiency source	Efficiency with ballast	Chemical action AgCl paper	Chemical action yellow paper	Relative actinic activity	Chemical efficiency AgCl	Chemical efficiency yellow	UV loss through glass %
Metal filament lamp	40–25	48.3	48.3	1.2	1.2	0.414	—	1	1	—	—
Arc lamp, red	1010	609	1650	0.602	1.63	58.2	18.3	5.6	0.243	0.82	50
Arc lamp, yellow	1990	595	1738	0.300	0.875	82.5	25	4	0.152	0.502	37
Ordinary arc lamp	2500	990	2180	0.396	0.875	115	64.5	5.65	0.129	0.29	30
Arc lamp, white (bluish)	1990	589	1628	0.297	0.845	320	6.1	15.5	0.045	0.24	25
Arc lamp, white (reddish)	2940	600	1694	0.221	0.62	355	7.4	11.7	0.0445	0.214	45
Mercury vapour lamp (ordinary)	765	258	437	0.34	0.57	33	3.3	6.7	0.0713	1.15	—
Mercury vapour lamp (quartz)	1300	352	484	0.27	0.37	267	16.7	20.7	0.015	0.24	83

could not be used satisfactorily because the printing paper darkened too rapidly. A darker standard tone was therefore adopted, consisting of 10 parts lampblack to 1000 parts zinc oxide.

The results obtained are summarised in the preceding table.

In calculating the power consumption of the lamps, account was taken both of the actual electrical power consumed and of the total power required when each lamp was operated from a 110-volt supply, including the energy unavoidably dissipated in the ballast resistor.

The measured values of chemical intensity were recalculated to correspond to a distance of 1 metre between the light source and the photometer, with an exposure time of 1 hour. Since the chemical effect of a standard benzine lamp was too weak, a 110-volt metal-filament incandescent lamp having a luminous intensity of 40.25 Hefner candles (HK) and a power consumption of 1.2 watts per HK was adopted as the comparison light source, and its **relative actinity**

$= \frac{\text{chemical brightness}}{\text{optical brighness}} = 1$ taken as the standard.

The Küch quartz lamp occupies by far the highest rank with respect to relative actinity. Likewise, in terms of chemical efficiency for chloride-silver printing papers, it proved to be the best.

For the bichromate process, the results are even more favourable for the quartz lamp, since violet light is absorbed by the yellow pigment to a lesser extent.

Finally, the loss of ultraviolet radiation caused by interposing a glass plate was determined by comparison with a rock-crystal (quartz) plate.

A practical experiment confirmed the values obtained and reported in the preceding table in every respect.